NOV Green Hydrogen Product Offerings

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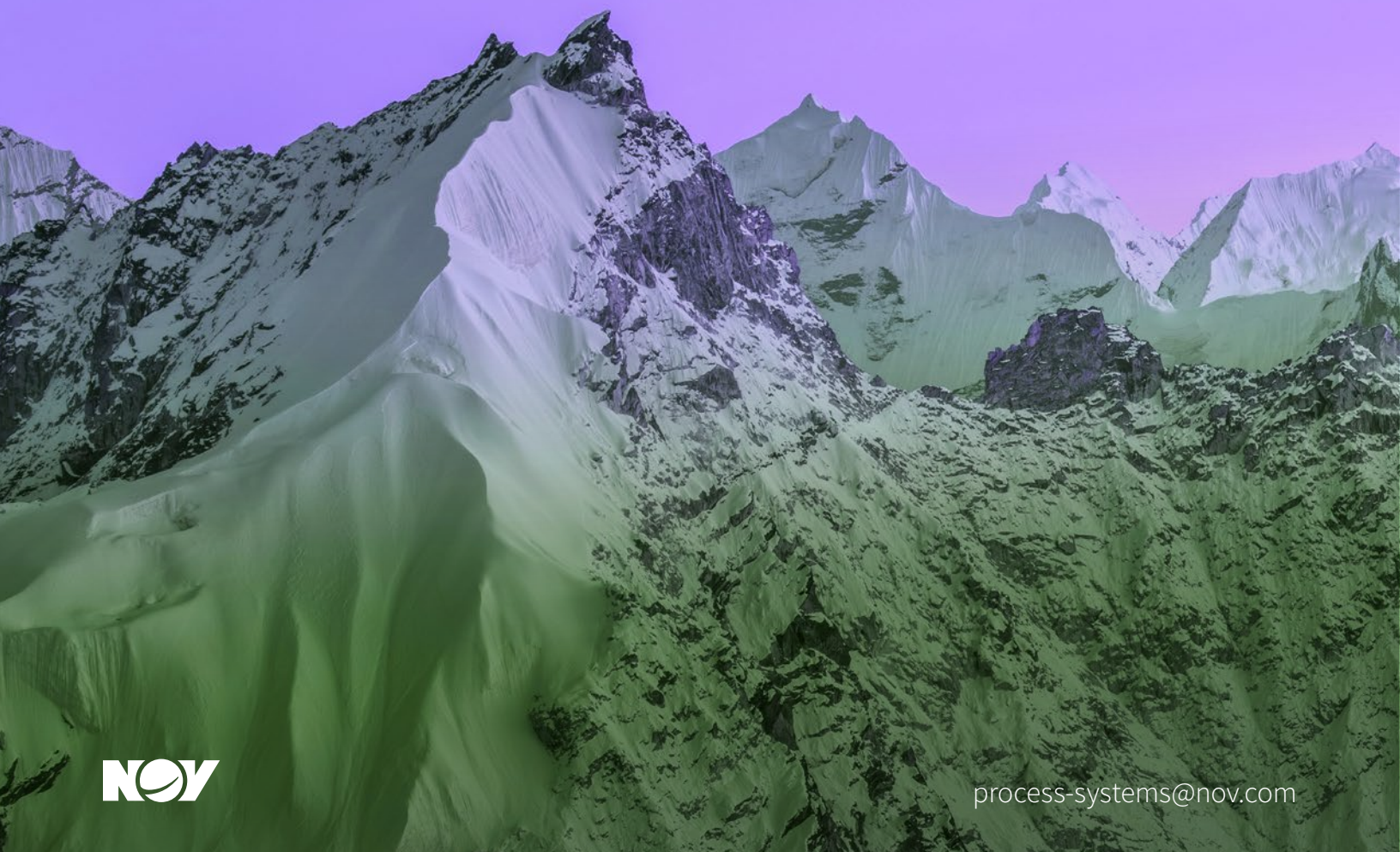

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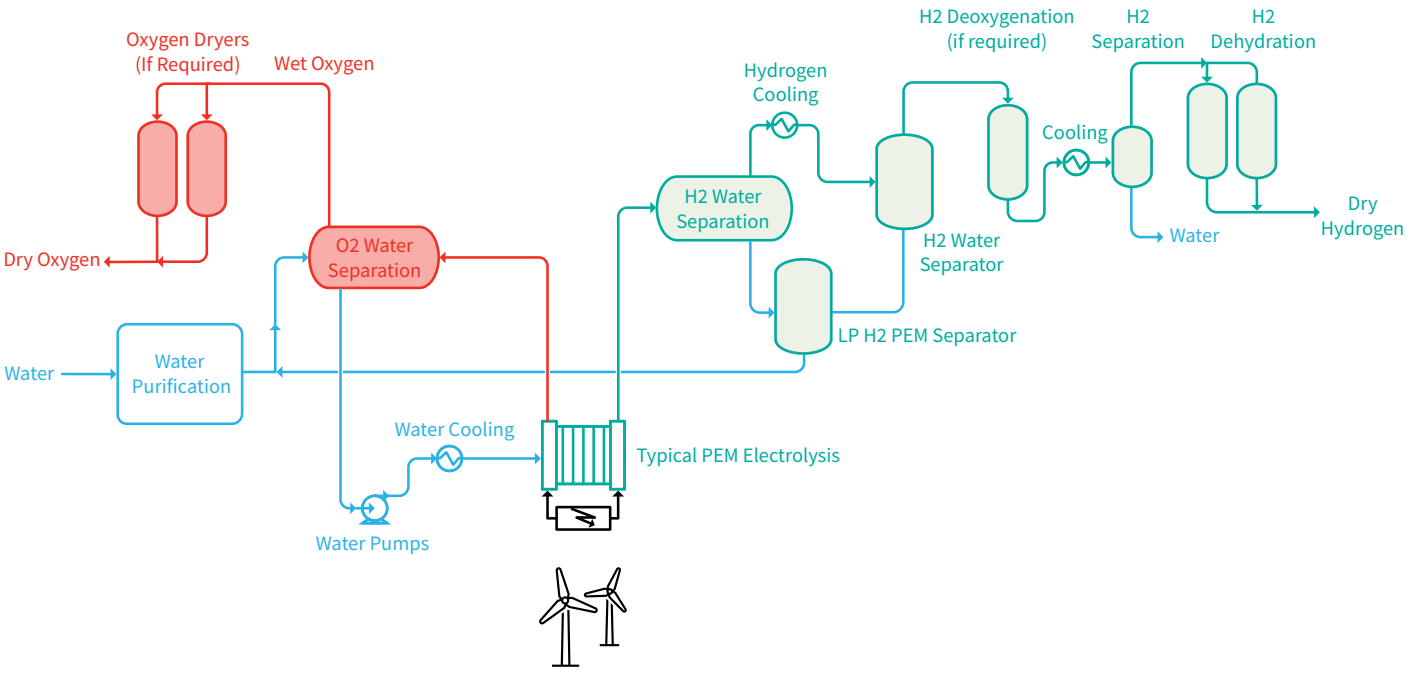
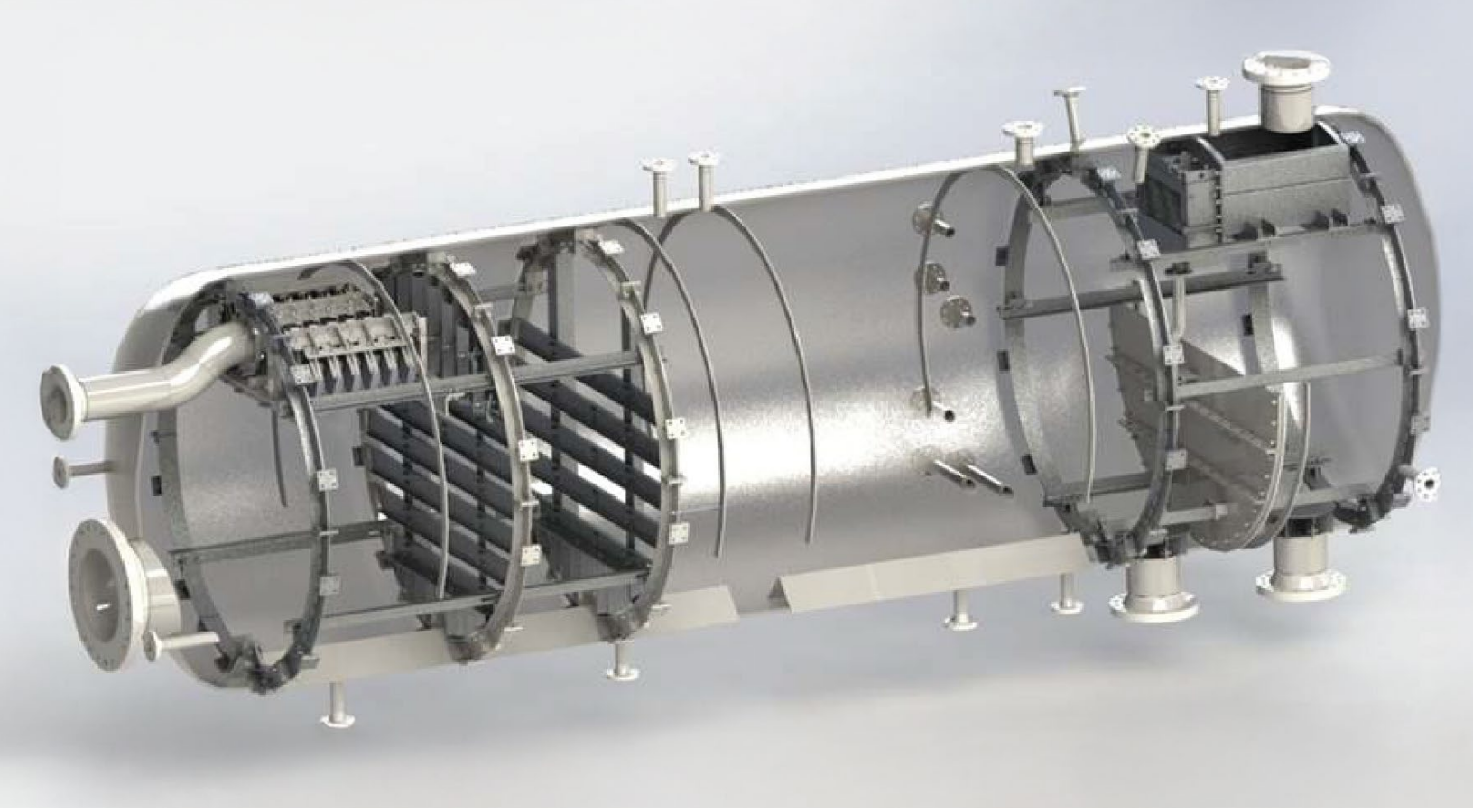
Green Hydrogen Processing Overview

Green hydrogen, produced through water electrolysis powered by renewable energy, is a pivotal component of the expanding global energy mix. However, the levelized cost of electricity and production efficiency significantly impact its economic viability.

NOV offers the next generation of gas processing and separation solutions for green hydrogen, designed to handle intermittency, turndown, and efficiency requirements. These processes ensure the purity and quality of hydrogen, which is crucial for its application across various industries, including ammonia, chemical production, and energy storage and transportation.

As a leading global provider of gas purification, separation technology, and equipment, we bring extensive expertise in deploying hydrogen separation, deoxygenation, and dehydration systems throughout the world. NOV can help you assess which technology best suits any given application.

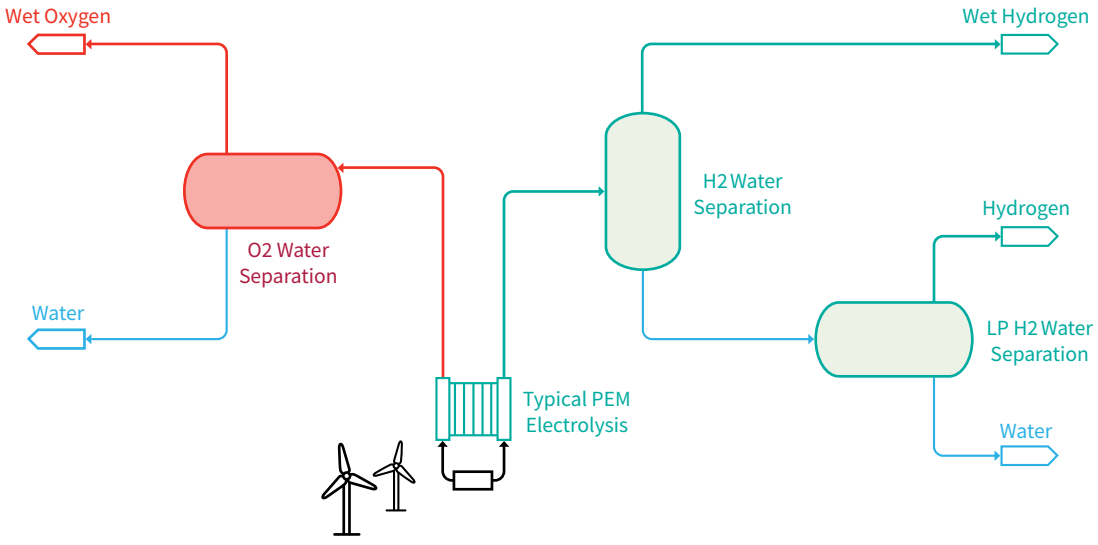




Separation

Hydrogen produced through water electrolysis creates oxygen and hydrogen as the two primary products. These streams will not be pure and will contain liquid water and potentially other chemicals, depending on the electrolysis type. We offer various solutions to meet your separation, turndown, and capacity requirements. The ease of integrating efficient separation equipment with compact, cost-effective solutions improves operating performance and reduces overall costs.

Separation at a glance



Our Separation offering:

- Meets the hydrogen and oxygen separation requirements of your project
- H_2S removal
- KOH removal
- Direct contact cooling and separation
- Catalysts and adsorbents
- Coalescer filters
- Water separation
- Specialized internals
- Customized solutions for the most challenging projects
- Standardized solutions for fast deployment

Separation Internals comprise:

- Specialized inlet devices
- Plate pack coalescer
- Flow distribution plates
- Demister
- Flexible design for efficiency, pressure drop, and turndown ratios

Other services offered:

- World-class testing facility
- CFD design verifications

We provide efficient, optimized process design, fabrication, and package delivery for green hydrogen separation systems. Whether supporting a full-scope or split-scope project, we tailor each solution to your requirements. We collaborate with EPC firms, electrolyzer manufacturers, project developers, operators, and consortiums to support a wide range of project needs.

Separation offering

- **Typical hydrogen flow capacity:** ~4.5 to 450 TPD (10 to 1000 MW)
- **Inlet composition:** Flexible composition
- **Upstream:** Flexible electrolyzer technology
- **Constructability:** Customizable or standardized offerings

Notable features and benefits:

- Wide operating range
- Efficient and customizable
- High turndown ratios
- Enable compact and high-performance separation

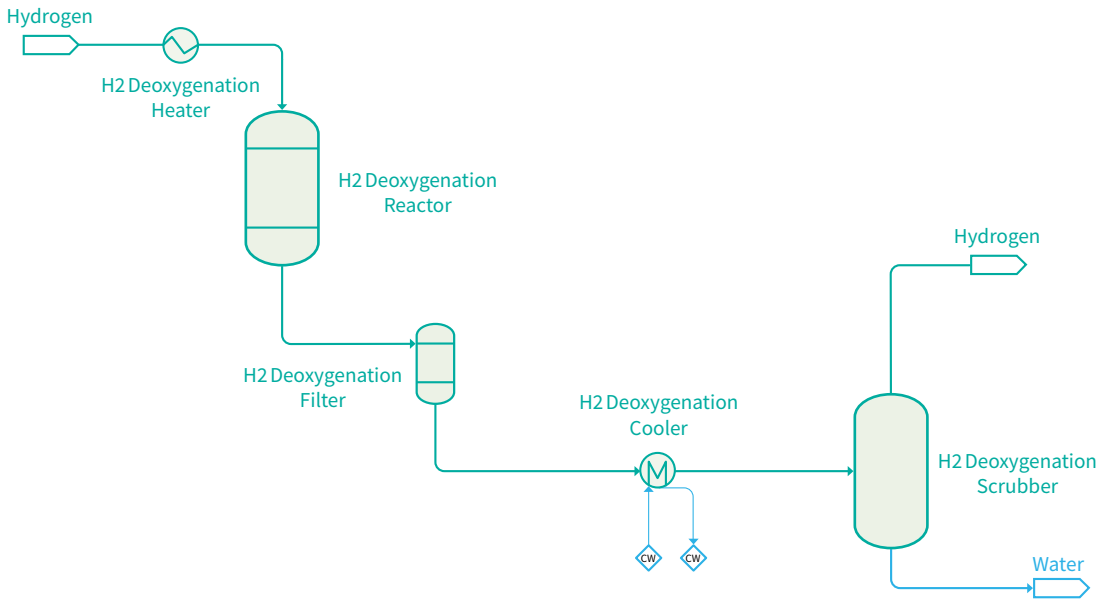
Applications and Separation Solutions for:

- PEM electrolyzers
- AEM electrolyzers
- Alkaline electrolyzer
- Hydrogen Storage

Hydrogen Deoxygenation

Hydrogen deoxygenation technology is a catalytic reaction that involves passing the hydrogen gas stream through a catalyst bed, where oxygen reacts with hydrogen to form water. It offers a low-energy, low-cost, and simple method for removing oxygen. Deoxygenation is typically designed to achieve oxygen levels between 1 and 10 ppmv to meet industry specifications.

Deoxygenation at a glance



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Our Hydrogen Deoxygenation offering:

- Meets the hydrogen specifications of your project (fuel cell, ammonia, efuels, etc.)
- Mechanism for oxygen removal by hydrogen reaction: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$
- Customized skids/modular solutions for the most challenging projects
- System integration with dehydration for seamless and optimized hydrogen purification
- Provides the lowest OPEX solution for long-term operation
  - Long bed life
- Flexible design for any green hydrogen developments, pressure drop, and turndown ratios
- Incorporation of health, safety, and environmental control

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Hydrogen Deoxygenation offering

- **Typical hydrogen flow capacity:** ~4.5 to 450 TPD (10 to 1000 MW)
- **Inlet composition:** ~saturation and variable oxygen content
- **Operating temperatures:** typically > 30°C (86°F)
- **Upstream:** Flexible electroylzer technology
- **Technology:** catalytic reaction with platinum or palladium catalyst
  - BASF Purivate™
  - BASF Puristar®
- **Constructability:** Customizable, stick-built, or modular

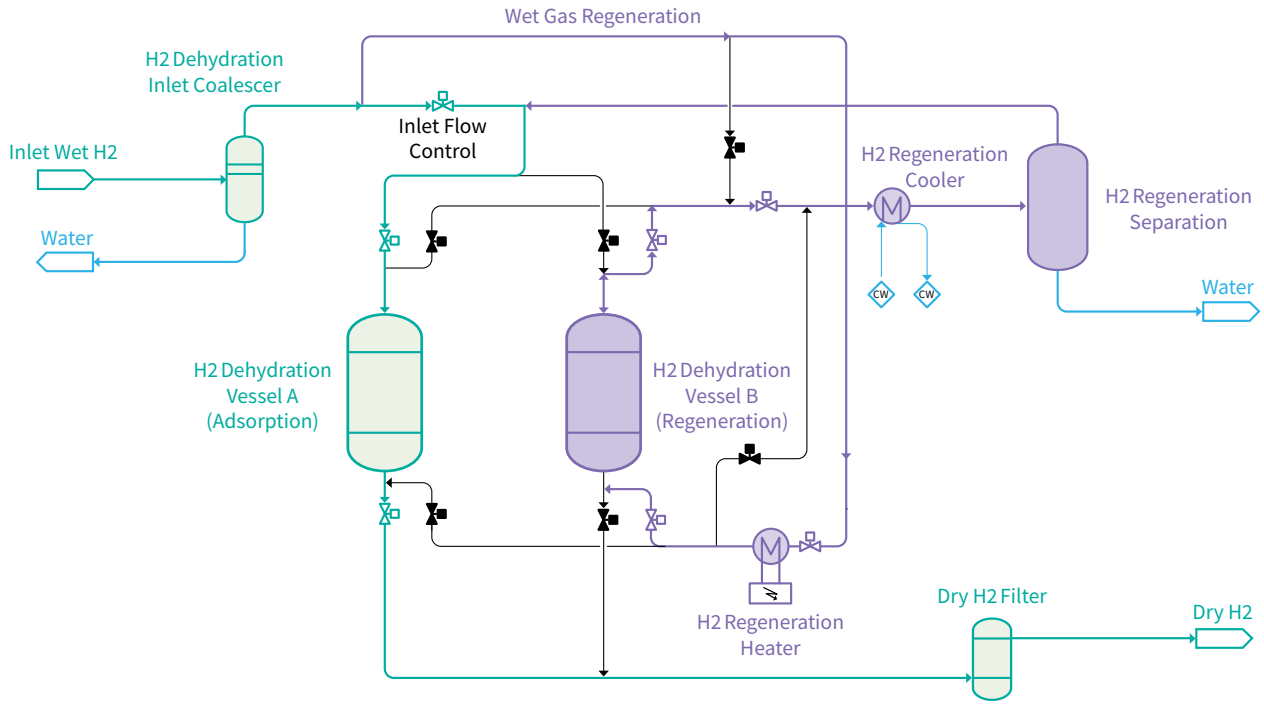
Notable features for Deoxygenation:

- Suitable for oxygen removal down to 1 ppmv
- Fast start-up times
- High turndown ratios

Hydrogen BASF Sorbead® Dehydration

BASF Sorbead® Dehydration technology is a temperature swing adsorption (TSA) process that involves passing the hydrogen gas stream through a Sorbead aluminosilicate media bed, which has a high affinity for water molecules. The Sorbead media bed is then regenerated through heat. It offers a balanced, low-energy, low-cost, and simple method for low moisture levels. The low energy conditions and ease of regenerating the Sorbead bed in a cyclic manner while achieving low water content in the dried hydrogen make this process a very appealing solution. Sorbead dehydration technology solutions are typically recommended for 5 to 50 ppmv water content specifications of produced hydrogen gas.

TSA with wet gas regeneration at a glance



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Our Hydrogen BASF Sorbead® offering:

- Meets the hydrogen and oxygen dryness specifications of your project (fuel cell and other applications at 5 ppmv moisture content)
- Customized modular solutions for the most challenging projects
- Configurable solutions for fast deployment
- Wet gas regeneration or dry gas regeneration configuration
- Provides the lowest OPEX solution for long-term operation
  - Lower regeneration temperatures compared to molecular sieve media
  - Longer bed life compared to molecular sieve media
  - Smart Bed™ digital solution
- Flexible design for dehydration efficiency, pressure drop, and turndown ratios
- Incorporation of health, safety, and environmental control

We provide efficient, optimized process design, fabrication, and package delivery for green hydrogen separation systems. Whether supporting a full-scope or split-scope project, we tailor each solution to your requirements. We collaborate with EPC firms, electrolyzer manufacturers, project developers, operators, and consortiums to support a wide range of project needs.

Hydrogen BASF Sorbead® offering

- **Typical hydrogen flow capacity:** ~4.5 to 450 TPD (10 to 1000 MW)
- **Inlet composition:** ~saturation
- **Upstream:** Flexible electrolyzer technology
- **Technology:** TSA with aluminosilicate gel-based adsorbent
- **Constructability:** Customizable, modular, and stick-built options

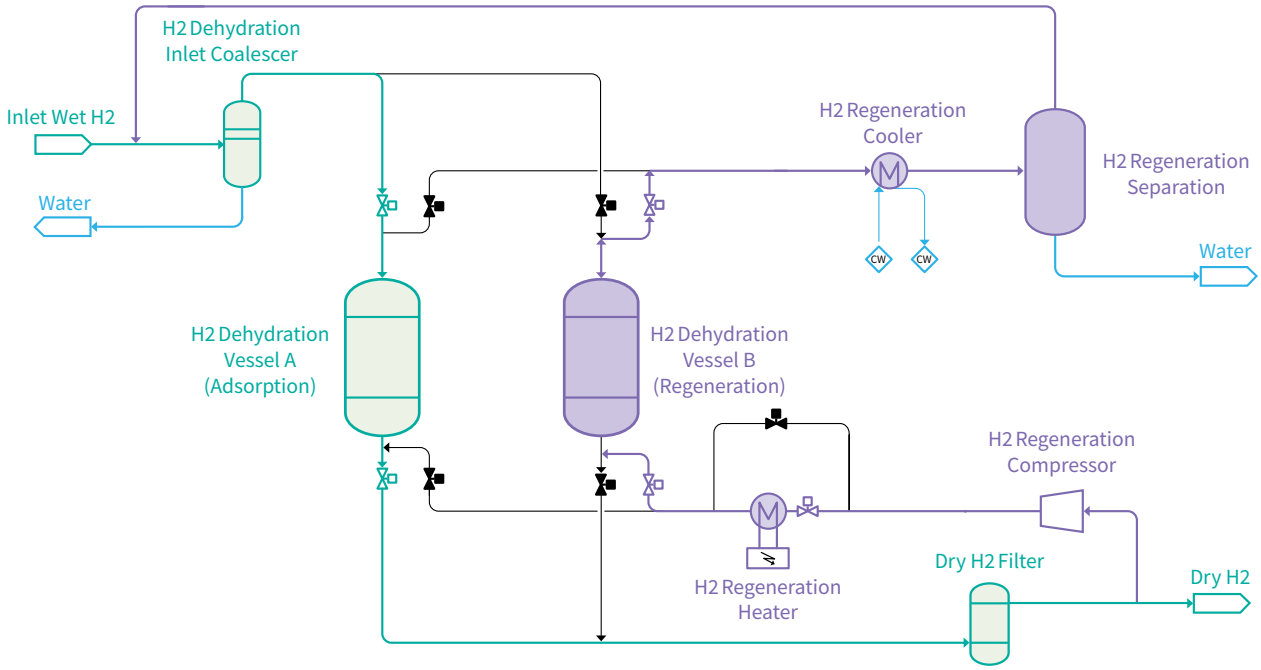
Notable features for TSA with BASF Sorbead®:

- Suitable for water dryness down to 5 ppmv
- Acid resistant
- Fast start-up times
- Lower regeneration temperatures
- High turndown ratios
- TSA with wet gas regeneration or dry gas regeneration configuration

Hydrogen Molecular Sieve Dehydration

Molecular Sieve Dehydration technology is a temperature swing adsorption (TSA) process that involves passing the hydrogen gas stream through a molecular sieve media bed, which has a high affinity for water molecules. The molecular system is then regenerated through heat. It offers a balanced, low energy, low cost, and simple method for ultra-low moisture levels. The ease of regenerating the molecular sieve bed in a cyclic manner while achieving low water content in the dried hydrogen makes this process a very appealing solution. Molecular sieve dehydration is typically recommended for 0.1 to 5 ppmv water content specifications.

TSA with wet dry regeneration at a glance



Our Hydrogen Molecular Sieve offering:

- Meets the hydrogen dryness specifications of your project (ammonia, efuel, and other low moisture content)
- Customized modular solutions for the most challenging projects
- Configurable solutions for fast deployment
- Wet gas regeneration or dry gas regeneration configuration
- Provides the lowest OPEX solution for long-term operation
- Smart Bed™ digital solution
- Flexible design for dehydration efficiency, pressure drop, and turndown ratios
- Incorporation of health, safety, and environmental control

We provide efficient, optimized process design, fabrication, and package delivery for green hydrogen separation systems. Whether supporting a full-scope or split-scope project, we tailor each solution to your requirements. We collaborate with EPC firms, electrolyzer manufacturers, project developers, operators, and consortiums to support a wide range of project needs.

Hydrogen Molecular Sieve offering

- **Typical hydrogen flow capacity:** ~4.5 to 450 TPD (10 to 1000 MW)
- **Inlet composition:** ~saturation
- **Upstream:** Flexible electrolyzer technology
- **Technology:** TSA with molecular sieve-based adsorbent
- **Constructability:** Customizable, stick-built, or modular

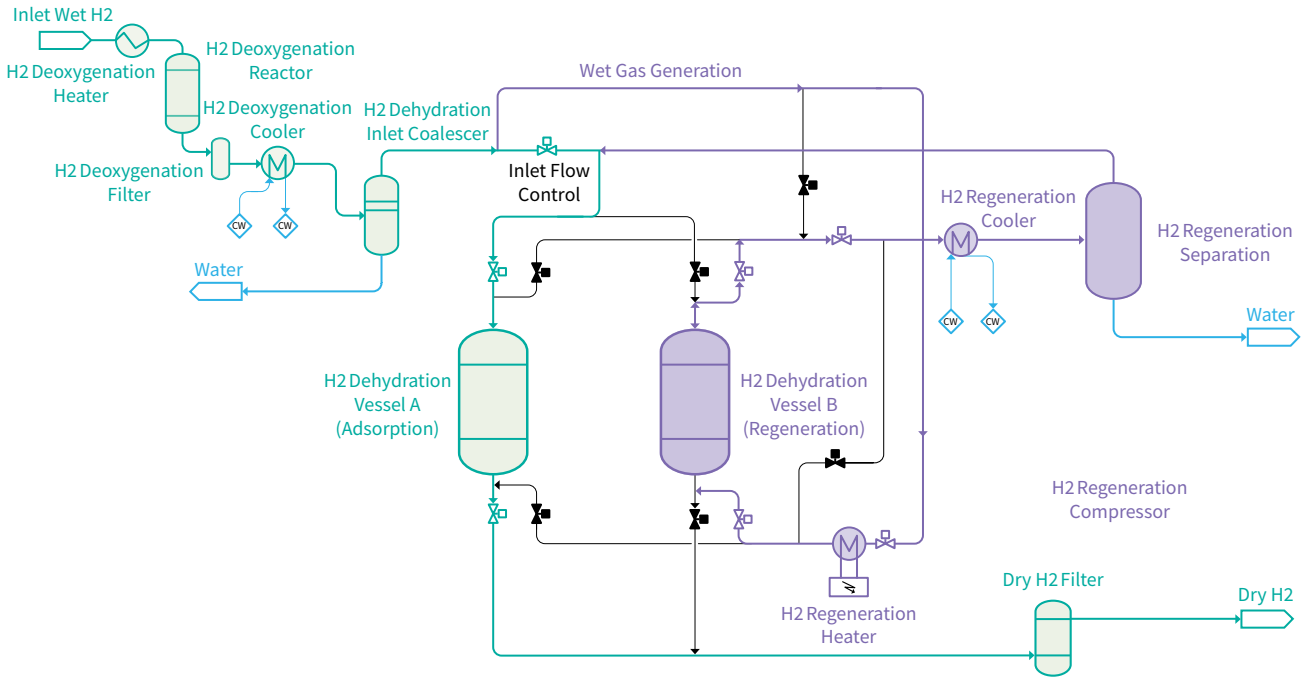
Notable features for TSA with Molecular Sieve:

- Suitable for water dryness down to 0.1 ppmv
- Fast start-up times
- Intermittency suitable
- High turndown ratios
- TSA with wet gas regeneration or dry gas regeneration configuration
- Options for H_2S & Water removal

Hydrogen Purification

Hydrogen purification technology is a combined deoxygenation and dehydration system-based temperature swing adsorption (TSA) process that involves passing the hydrogen gas stream through a catalyst bed to remove oxygen before passing through a solid adsorbent media bed for final dehydration. It offers a compact and integrated system to maximum efficiency to cater to the green hydrogen demands of high turndown, low energy, low cost, and simple method for dehydration. The ease of regenerating the adsorbent media bed in a cyclic manner while achieving low water content in the dried hydrogen gas makes this process a very appealing solution. Hydrogen dehydration is typically required to meet moisture specifications of 0.1 to 5 ppmv water.

H2Pure with wet gas regeneration at a glance



Our Hydrogen purification offering:

- Meets the hydrogen, oxygen, and moisture specifications of your project (fuel cell, ammonia, efuel)
- Customized modular solutions for the most challenging projects
- Configurable solutions for fast deployment
  - 50 MW green hydrogen capacity
  - 100 MW green hydrogen capacity
- Wet gas regeneration or dry gas regeneration configurations
- Provides the lowest OPEX solution for long-term operation
  - Smart Bed™ digital solution
- Flexible design for dehydration efficiency, pressure drop, and turndown ratios
- Incorporation of health, safety, and environmental control

We provide efficient, optimized process design, fabrication, and package delivery for green hydrogen separation systems. Whether supporting a full-scope or split-scope project, we tailor each solution to your requirements. We collaborate with EPC firms, electrolyzer manufacturers, project developers, operators, and consortiums to support a wide range of project needs.

Hydrogen purification offering

- **Typical hydrogen flow capacity:** ~110, 220 TPD and above + TPD (50 MW, 100 MW and above)
  - **Inlet composition:** ~saturation
  - **Upstream:** Flexible electrolyzer technology
  - **Technology:** Deoxygenation and TSA with molecular sieve or BASF Sorbead® dehydration media

- **Constructability:** Modular or customized stick-built

Notable features for Hydrogen purification:

- Suitable for oxygen down to 1 ppmv
- Suitable for water dryness down to 0.1 ppmv
- Fast start-up times
- Intermittency suitable
- High turndown ratios
- TSA with wet gas regeneration or dry gas regeneration configuration
- Multibed TSA options

Smart Bed Dehydration Control

The Smart Bed™ Dehydration Control system for temperature swing adsorption (TSA) units is a configuration and control system methodology that allows monitoring of the adsorption beds to tune the switching from adsorption to desorption on a system-needs basis, as compared to traditional, simple time-based control. With Smart Bed Dehydration Control, the adsorbent media bed adsorption time can be extended. By increasing the adsorption time, the frequency of regeneration cycles is reduced, and thus overall energy consumption can be reduced, along with increasing the desiccant media lifetime.

Green hydrogen production facilities are directly linked to the availability of green power sources. Some green energy sources such as solar and wind are limited to time of day, seasons, and other environmental factors, resulting in variation in power availability and thus production rates. This variation of production can be controlled easily with TSA dehydration systems. The Smart Bed™ Dehydration control system takes the control beyond specification requirements and enhances the process for energy and cost management. As an indicative benefit assessment, the reduction in regeneration cycles can be directly linked to the average power availability. Lower power availability, as typically seen with wind and solar energy, leads to greater reductions in regeneration cycle frequency. Most of the power consumption of the TSA systems relates to the number of regeneration cycles. With Smart Bed Dehydration Controls, we can reduce facility power and costs for effective dehydration of hydrogen gas streams.

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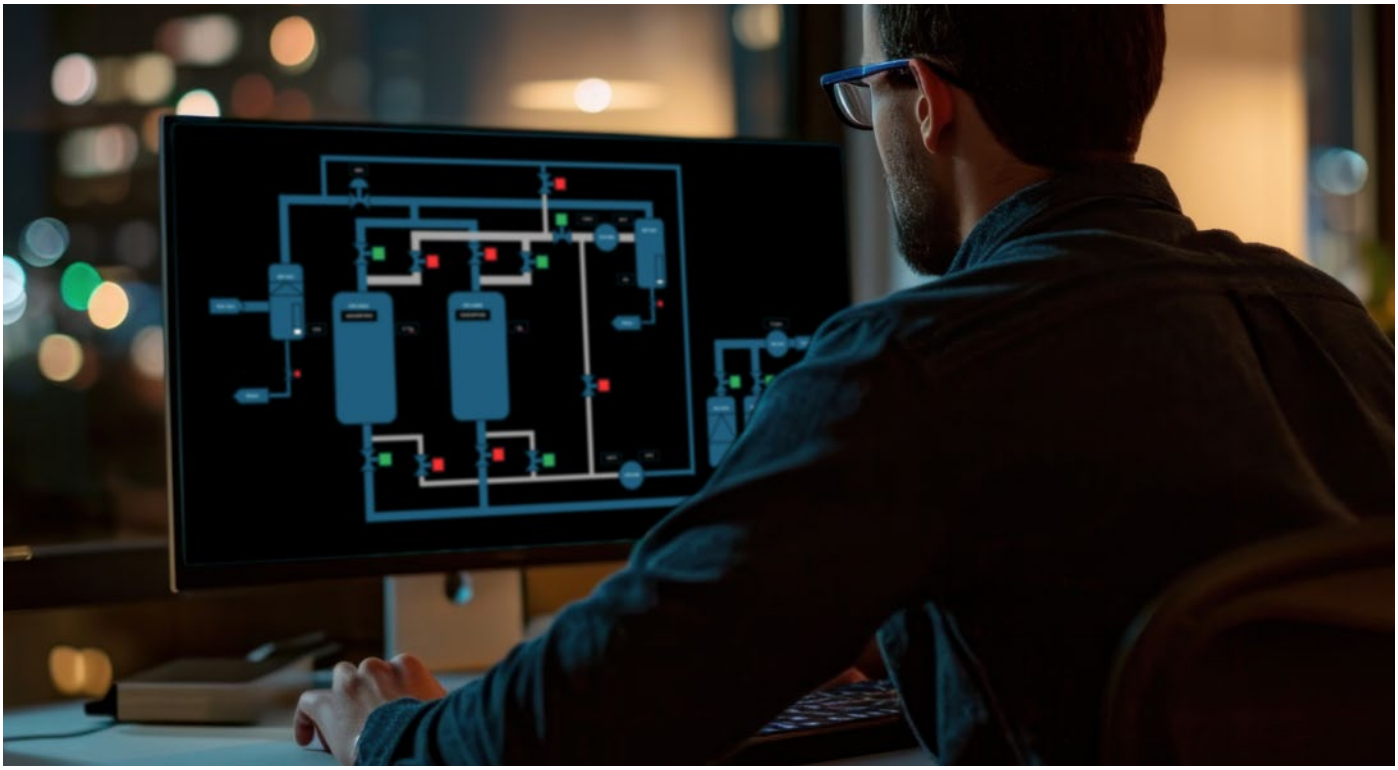
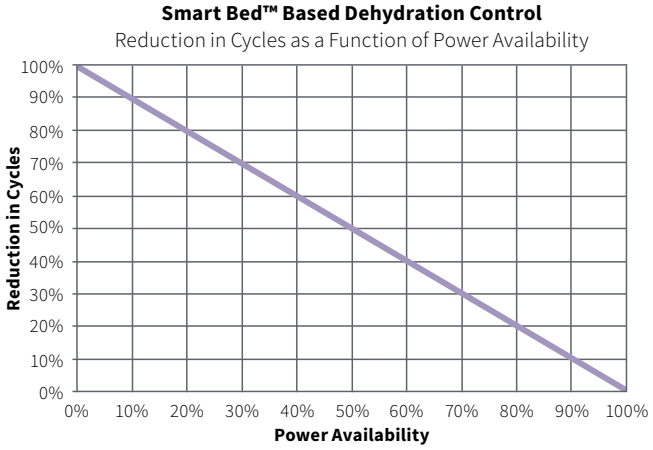


The primary operating costs of a TSA system are media regeneration heating and media replenishment. Both can be reduced by implementing a Smart Bed Dehydration Control system, which minimizes regeneration cycles by triggering off bed media loading signals. Fewer cycles of a TSA system not only lower annual regeneration costs and associated emissions, but also reduce the number of heat cycles on the adsorbent, extending media life.

Maximize your output by minimizing your input by using Smart Bed.



Reduced Operating Costs

Reduced Energy

Increased Bed Life

We leverage these inherent variations to optimize your operating costs.

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